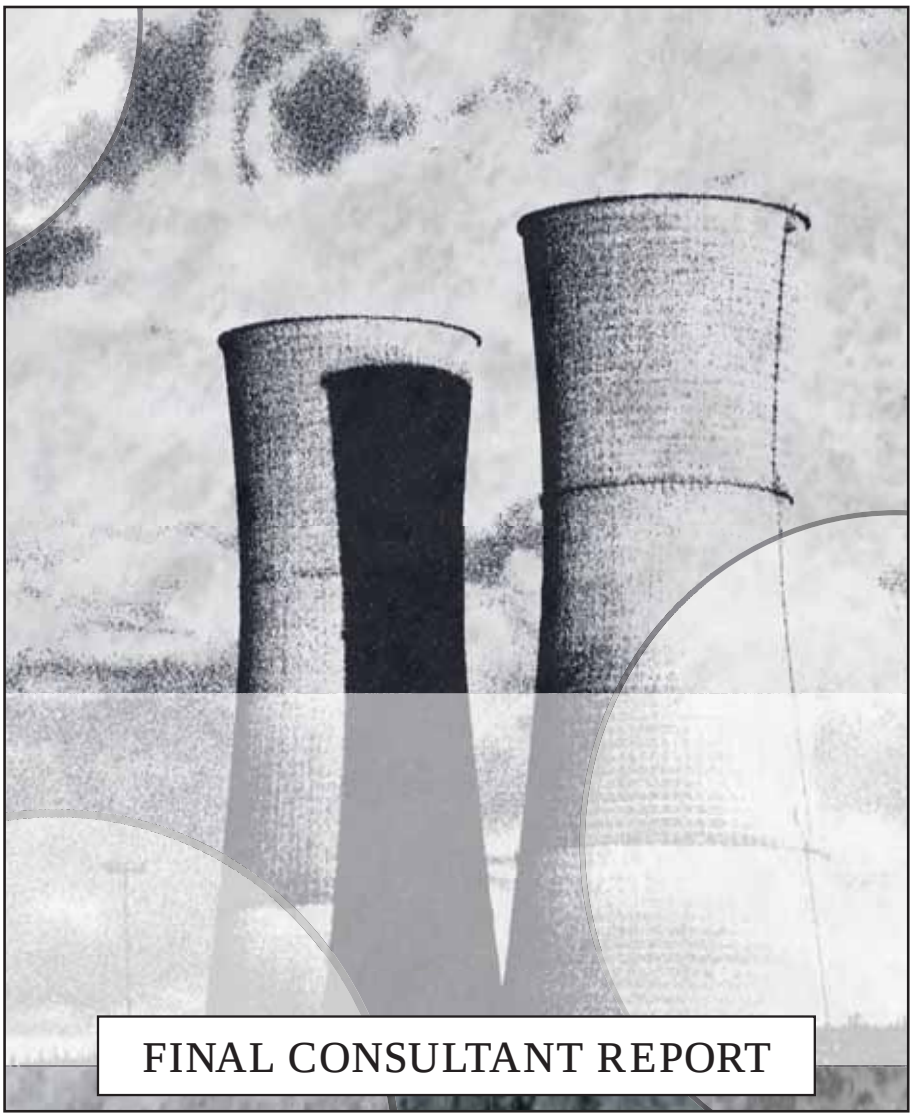
NUCLEAR POWER in CALIFORNIA: 2007 STATUS REPORT



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Additional Reading

This report does not attempt to provide an in-depth background on nuclear power technology, as this is already done in many excellent books and articles. See, for example, *Megawatts and Megatons* by Dr. Richard Garwin and Dr. Georges Charpak (Garwin 2001), *The Future of Nuclear Power: An Interdisciplinary MIT Study* (MIT 2003), and *Benefits and Risks of Nuclear Power in California* by Roger Dunstan (Dunstan 2002). In addition, the 2005 Energy Commission Consultant Report, *Nuclear Power in California: Status Report*, provides background on many of the issues discussed in this report, and the expert consultant report released by the Keystone Center in 2007, *Nuclear Power Joint Fact-Finding*, complements many sections of this report.

Abstract

This consultant report examines how nuclear power issues have evolved since publication of the consultant report, *Nuclear Power in California: Status Report,* which was prepared for the *2005 Integrated Energy Policy Report* (*2005 IEPR*). The report focuses on four broad subject areas: 1) nuclear waste issues, 2) costs of nuclear power, 3) environmental and societal impacts of nuclear power, and 4) nuclear power in the United States in the coming years. Nuclear waste issues include the status of a federal repository at Yucca Mountain, the proposed federal reprocessing program, and issues related to the transportation of nuclear waste. The costs of nuclear power are addressed from three angles: the costs of operating California's current nuclear power plants, the costs of building and operating new nuclear power plants, and the cost implications of a "nuclear renaissance." Environmental and societal impacts discussed include the environmental implications of nuclear power, the role of nuclear power in climate change policy, and the security implications of nuclear power generation. Finally, the future of nuclear power is addressed by considering the safety and reliability of the aging U.S. nuclear fleet, license extensions that could keep the current fleet operating for an additional 20 years, and the development of new nuclear power plants in the United States. The report concludes by offering potential implications for California from these events.

Keywords

nuclear, nuclear power, nuclear waste, spent fuel, Yucca Mountain, interim spent fuel storage, reprocessing, Global Nuclear Energy Partnership, uranium, enrichment, greenhouse gas, once-through cooling, license renewal, relicensing, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Humboldt Bay, Rancho Seco, SMUD, NRC, Nuclear Regulatory Commission, U.S. Department of Energy, DOE, electricity, policy, California

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EXECUTIVE SUMMARY

Nuclear power generation has played an important role in California's electric generation system for more than two decades. Because of the intense public interest and the wide range of public policy questions raised by nuclear power, the California Energy Commission (Energy Commission) was tasked by the Legislature in 1976 to examine key questions that lay at the heart of the nuclear power enterprise. As a result of that examination, undertaken early in the Commission's existence, state policy on nuclear power development has been clearly established over the past 30 years: existing plants can continue to operate, but development of new nuclear plants is contingent on the demonstration and approval of the technologies needed to reprocess or dispose of the spent fuel generated in nuclear reactors.[1]

Recent interest in nuclear power led the Commission to renew its scrutiny of nuclear issues. As part of the *2005 Integrated Energy Policy Report (IEPR)* process, the Commission reviewed the status of nuclear power as an energy resource for California.[2] Based on that review, supported by a comprehensive status report and a two-day workshop that brought together a wide range of nuclear energy experts, the Energy Commission found, as it had in 1978, that a technology for the permanent disposal or reprocessing of high-level waste had not been demonstrated nor approved for use in the United States.[3] Consequently, according to California law, the Energy Commission could not provide land-use permits or certification for a new nuclear power plant in California. (Additional findings and recommendations of the *2005 IEPR* are shown on the following page.)

Since the release of the *2005 IEPR,* the renewed interest in nuclear power has continued in the United States, driven in part by considerable federal subsidies offered for new nuclear power plants, concerns about the impacts of greenhouse gas emissions, and volatility in fossil fuel prices. With this renewed interest, the role of nuclear power has taken on greater visibility and importance. The Energy Commission is engaged in reviewing the issues associated with nuclear power as they relate to California policy. This report, *Nuclear Power in California: 2007 Status Report*, has been prepared to support the review undertaken as part of the Commission's *2007 IEPR process*. The major conclusions from this report are described below. Implications for the state are summarized at the end of the Executive Summary and discussed in more detail in the report.

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[1] California's nuclear legislation is provided in Appendix A. Energy Commission reports related to this legislation are available on the Energy Commission's website: http://energy.ca.gov/2007_energypolicy/documents/index.html#06252807.

[2] The *2005 Integrated Energy Policy Report* is available at the Energy Commission's website: http://energy.ca.gov/2005_energypolicy/documents/index.html.

[3] The status report, *Nuclear Power in California: Status Report*, and material from the 2005 workshop are available at the Energy Commission's website: http://energy.ca.gov/2005_energypolicy/documents/2005_index.html#0815+1605.

2007 Status Report Conclusions

A repository at Yucca Mountain is still at least a decade away from being opened, and the opening date continues to slip. Alternatives to Yucca Mountain are being considered because of concerns about the viability of the repository. California utilities should therefore continue to plan for indefinite storage of spent fuel at power plant sites and should continue to move spent fuel to on-site dry cask storage facilities. The Energy Commission will examine the implications of extended on-site storage in its AB 1632 study.[4]

Even with higher uranium prices, reprocessing of spent fuel is more expensive than a "once-through" fuel cycle. Current reprocessing technologies do not provide substantial waste management benefits, nor do they address nuclear weapons proliferation concerns. The federal Global Nuclear Energy Partnership (GNEP) remains poorly defined, and new technologies that might result from that program could either exacerbate or alleviate waste management and nonproliferation concerns. It will be decades before new reprocessing and reactor technologies resulting from the Global Nuclear Energy Partnership could be introduced on a wide scale, and it is not known today what the costs and benefits might be.

2005 IEPR Key Findings and Recommendations on Nuclear Power

A high-level waste disposal technology has been neither demonstrated nor approved.

Reprocessing remains substantially more expensive than waste storage and disposal and has substantial adverse implications for U.S. efforts to halt the proliferation of nuclear weapons.

The Legislature should develop a suitable state framework to review the costs and benefits of nuclear power plant license extensions. The state should consider the potential extensions of operating licenses, along with other resource options.

The state should evaluate the long-term implications of the continuing accumulation of spent fuel at California's operating plants.

The state should evaluate the implications of DOE's increasing use of California routes for shipments of nuclear waste to and from Nevada, and the precedent this could set for route selection of future shipments to Yucca Mountain.

California should reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments.

The federal government should return some portion of the funds paid by California ratepayers for a permanent national repository for nuclear waste to pay for interim storage of waste at California reactor sites.

[4] California Assembly Bill 1632 requires the Energy Commission to assess the potential vulnerability of nuclear power plants to major disruptions, the costs and impacts of accumulating waste at reactor sites, and other key policy and planning issues related to nuclear power (AB 1632 2006).

Nuclear waste can be transported safely with manageable risks to the public if shipments are conducted in strict compliance with existing regulations, but constant vigilance is required. Although extreme accidents are unlikely, their probability can be reduced through route-specific analyses to identify and diminish potential hazards. Greater information sharing by the Department of Energy (DOE) regarding spent fuel transport routes and plans is needed to allow state and local input and to gain public confidence in these shipments. California could be strongly affected by repository shipments, since many spent fuel and high-level waste shipments could be routed through the state en-route to Yucca Mountain.

The cost of power from California's currently operating nuclear plants will be driven largely by the cost of the steam generator replacement projects and any other large capital projects that are required as the plants age and by plant overall performance. Unexpected long-term outages, additional security requirements, and new once-through cooling regulations could also affect nuclear costs.

Cost estimates for new nuclear plants range widely and appear to have increased significantly in recent years. Federal incentives have fueled interest in new reactors; however, it remains to be seen to what extent that interest will translate into actual new development. A key issue will be the allocation of costs and risk for proposed new nuclear projects.

Increases in the prices for nuclear fuel, reactor materials, and skilled labor are likely if many new reactors are built, either in the United States or abroad. Supply constraints could limit the development rate and increase the costs of new reactors.

Nuclear power generates greenhouse gas emissions throughout its life cycle at a scale comparable to renewable power. However, nuclear power poses specific environmental risks, including aquatic impacts from once-through cooling; radiation hazards associated with mining, milling, and waste disposal; and potentially severe impacts from accidents or terrorism. Because of these concerns, as well as the uncertain costs and long development time for new nuclear plants, the proper role for nuclear power in a greenhouse gas reduction plan is the subject of heated debate. The resolution of that debate will depend on the costs and development rate for all low-carbon resources.

Malevolent acts against nuclear power plants or spent fuel and high-level waste shipments are a major concern. U.S. Nuclear Regulatory Commission (NRC) consideration of security issues for nuclear power plants and spent fuel transport has taken place with limited public scrutiny. The National Academies recommended that an independent examination of security risks be conducted and that the findings and recommendations from this study be made available to the public as much as possible. Improved information sharing, without compromising public safety, would strengthen public confidence in NRC security regulation and oversight.

The decline in performance at the Palo Verde plant, if continued, could have a significant effect on the availability of power in Southern California. The difficulty in identifying and resolving the root causes of this decline suggests that regulators need a more effective means to monitor plant performance and safety culture issues at aging nuclear plants.

Pacific Gas and Electric (PG&E) and Southern California Edison (SCE) are evaluating (or plan to begin evaluating) license renewals for their nuclear plants. The scope of issues considered in NRC license renewal proceedings is extremely limited and focuses primarily on plant hardware and plant aging considerations. As a result, the state will have a limited opportunity to address concerns in these proceedings. However, state regulators will separately evaluate the need and alternatives for these facilities and the impacts of cooling water requirements. State regulators may also undertake a reexamination of seismic requirements and land-use issues.

Nuclear Power in California

Nuclear power plants generate a significant share of California's electricity and provide significant benefits to the state. Nuclear power plants also impose significant costs, risks, and impacts. This is the essence of the "Faustian Bargain" described by nuclear pioneer Alvin Weinberg in 1970. Weinberg called on his colleagues to "weigh, and reweigh...the other side of the balances: the risks in our energy source" (Weinberg 1994, p.175). California's policy toward nuclear power reflects this balance, as the state relies upon existing reactors for a significant portion of its baseload electricity supply while prohibiting construction of new reactors until progress is demonstrated in the disposal of spent fuel.

California relies today on three nuclear power plants for 13 percent of the state's overall electricity supply:[5]

- Diablo Canyon Power Plant, owned by PG&E, is a 2,174 megawatt plant located near San Luis Obispo on the Central California coast.
- San Onofre Nuclear Generating Station (Units 2 and 3) is a 2,150 megawatt plant co-owned by SCE, San Diego Gas and Electric, and the City of Riverside. SCE operates the plant, which is located on the Southern California coast between Los Angeles and San Diego.
- Palo Verde Nuclear Generating Station, 3,733 megawatt plant, is co-owned by Arizona Public Service Corporation, SCE, and five other utilities. California utilities own 27 percent of the plant. Arizona Public Service Corporation operates the plant, which is located near Phoenix in Wintersburg, Arizona.

[5] There are also three retired commercial nuclear power plants in California: Humboldt Bay, Rancho Seco, and San Onofre Unit 1.

These plants have operated for roughly 20 years and are now halfway through their 40-year license periods. Approximately half of the U.S. nuclear power plant operators have received approval from the NRC for 20-year license extensions. PG&E, which owns and operates the Diablo Canyon Power Plant, is beginning a license renewal feasibility study for Diablo Canyon, and SCE intends to seek funding for a license renewal feasibility study for San Onofre in its upcoming rate case.

It is against this background that this report was prepared. The report is an update to the 2005 *Nuclear Power in California: Status Report* prepared for the *2005 IEPR*. The update examines the evolution of nuclear power issues since 2005 and has been informed by two days of public expert workshops at the Energy Commission and by public comments on the workshops and on a draft of this report.[6] It focuses on four broad subject areas: 1) nuclear waste issues, 2) costs of nuclear power, 3) environmental and societal impacts of nuclear power, and 4) nuclear power in the United States in the coming years. Based on that review, potential implications for California are discussed.

Nuclear Waste Issues

Three categories of nuclear waste issues are discussed in this report: storage and disposal of radioactive waste, reprocessing of spent fuel, and nuclear waste transport.

Storage and Disposal of Spent Fuel

In both the 2005 and 2007 proceedings it became clear that progress in designing and developing the Yucca Mountain high-level radioactive waste repository has been and continues to be problematic.

In 1982 Congress passed the Nuclear Waste Policy Act, creating a national program to permanently dispose of spent nuclear fuel and high-level radioactive waste produced by commercial nuclear power plants and defense nuclear weapons programs. The Act was amended in 1987 to focus on the Yucca Mountain site in Nevada as a permanent deep geologic repository for spent fuel and high-level radioactive waste.[7]

There is general agreement that such a geologic repository is the appropriate approach for the permanent disposal and isolation of spent fuel. Desirable characteristics for such a site, as described by the International Atomic Energy Agency include:

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[6] The draft report and workshop materials are available at the Energy Commission's website: http://energy.ca.gov/2007_energypolicy/documents/index.html#06252807.

[7] The Nuclear Waste Policy Act limits the capacity of Yucca Mountain to 70,000 metric tons of heavy metal (MTHM), which will be exceeded by the spent fuel from the current fleet of reactors. The technical capacity of Yucca Mountain is expected to be greater than the statutory limit.

- Long-term geologic stability;
- Stable geochemical and hydrochemical conditions at depth;
- Low groundwater content and flow at depth; and
- Engineering properties suitable for repository construction and operation.

The Yucca Mountain site does not exhibit the first two of these characteristics. This does not invalidate the site. However, it does mean that the repository will rely heavily on engineered, rather than geologic, barriers for preventing the leakage of radioactive materials into the environment and that DOE will face additional challenges in proving the viability of the site.

DOE was to begin accepting spent fuel for the repository by January 1998. Instead, nearly 10 years later, a repository at Yucca Mountain is still more than a decade away and the opening date continues to slip. As recently as 2005, DOE targeted a 2012-2015 opening date. However, DOE announced in 2006 that the earliest possible opening date is March 2017 and that a more realistic opening date is September 2020. Earlier this year DOE announced that the opening date is likely to slip an additional year. In addition, Nevada's powerful state public officials plan to cut funding and challenge every aspect of the Yucca Mountain project, making even this opening date highly uncertain.

The delay in opening the federal repository is a major stumbling block for the U.S. nuclear power industry. John Rowe, CEO of Exelon, the largest nuclear power operator in the United States, told shareholders in 2006 that he does not want to build a new nuclear power plant until the spent fuel disposal issue is solved: "We have to be able to look the public in the eye and say, 'If we build a plant, here's where the waste will go.' If we can't answer that question honestly to our neighbors, then we're playing politics too high for us to be playing" (Fortune Magazine 2006).[8]

In the *2005 IEPR*, the Energy Commission noted that "the federal waste disposal program remains plagued with licensing delays, increasing costs, technical challenges, and managerial problems" and that "Californians have contributed well over $1 billion to the federal waste disposal development effort." (Energy Commission 2005b, p.85), The Energy Commission recommended that some portion of these funds "be returned to the state to help defray the cost of long-term on-site spent fuel storage" and that the state "evaluate the long-term implications of the continuing accumulation of spent nuclear fuel at California's nuclear plants" (Energy Commission 2005b, p.85).

In the two years since the release of the *2005 IEPR* there have been a variety of developments but limited progress in addressing the waste disposal problem:

- DOE released a new schedule in 2006 for licensing and constructing the repository, including plans to submit its license application to the NRC in

[8] While Exelon is evaluating two possible sites for new nuclear power plants, Exelon has not yet decided whether to build either plant. (AP 2007a)

June 2008. DOE now acknowledges that Yucca Mountain is not likely to open before 2021.

- The U.S. Environmental Protection Agency (EPA) has yet to release final radiation protection standards for the Yucca Mountain repository to replace proposed standards that were remanded by the U.S. Circuit Court of Appeals in 2004. The EPA is already several months late in releasing the final version of these regulations.
- A number of bills intended to facilitate repository development were introduced in Congress in 2006, but none were passed. DOE officials have said that meeting DOE's "best achievable schedule" for the repository depends upon successful passage of Congressional legislation to expedite the repository project. Since the recent change in control of Congress, legislative action has focused on alternatives to the near-term completion of Yucca Mountain.
- In lawsuits against the DOE seeking restitution for interim storage costs, PG&E and the Sacramento Municipal Utility District were awarded $40 million each in compensation for dry cask spent fuel storage costs.
- A private off-site interim storage option, proposed to be built in Utah, was denied critical permits and likely will not be built.
- DOE's efforts to spur construction of new nuclear plants and to commercialize a new generation of reprocessing technology have raised concerns that the Yucca Mountain program might suffer from insufficient management and other resources.

In June 2007 the Keystone Center released the report of an expert consensus group, *Nuclear Power Joint Fact-Finding*.[9] For this report Keystone brought together representatives of government, academia, electric utilities, the nuclear industry, the financial community, and public policy groups, many of whom are generally found on "opposite sides of the fence" from each other on nuclear issues. The experts discussed the potential role of nuclear power in reducing climate change, the economics of nuclear power, safety and security of nuclear power, waste and reprocessing, and proliferation risks. They arrived at consensus views on many of these difficult issues.

On nuclear waste, the experts agreed that the best disposal option is a deep underground geologic repository, that the Yucca Mountain project "has repeatedly failed to meet its own schedule," and that there "is little confidence that currently established DOE schedules will be met" (Keystone 2007, pp.68, 70). They also agreed that spent fuel can be stored safely and securely at reactor sites and that centralized interim storage "is a reasonable alternative for managing waste from

[9] The Keystone Center is an independent nonprofit organization that brings together diverse stakeholders to build consensus on seemingly intractable public policy problems.

decommissioned plant sites and could become cost-effective for operating reactors in the future" (Keystone 2007, p.75).

Other experts and industry participants, including the National Commission on Energy Policy, are also looking to interim storage options considering the lack of progress toward opening a permanent repository. Some long-standing proponents of Yucca Mountain, including NRC Commissioner Edward McGaffigan, have suggested that it is time to re-examine the alternatives to Yucca Mountain. New interim spent fuel storage installations have been or are being constructed at all the reactor sites serving California. Regional storage proposals are under consideration, although these are generally opposed by state governments.

Low-Level Waste Storage

Low-level radioactive waste is not eligible for disposal at Yucca Mountain—disposal is a utility and state responsibility. According to California's regional compact with Arizona, North Dakota, and South Dakota, California would host the first commercial low-level waste facility to be opened in these states, and in the 1980s California selected Ward Valley in the Mojave Desert as a site for such a facility. However, the state was unable to purchase the site from the federal government, and no low-level waste facility has been built in the state.

Currently, California utilities dispose of low-level waste in facilities in South Carolina and Utah. Beginning in mid-2008 only the Utah facility will be available and only for the least radioactive grade of wastes. In the near term, once the South Carolina facility closes to California waste, California utilities will be forced to store higher grades of waste on-site.

Reprocessing of Spent Fuel

Under existing law California's moratorium on building new nuclear power plants will continue until a technology for the permanent disposal or reprocessing of spent nuclear fuel has been demonstrated and approved for use in the United States. In 1978 the Energy Commission found that high-level nuclear waste disposal technology had not been demonstrated nor approved by the authorized federal agency, that reprocessing technology had not been approved, and that reprocessing of light-water reactor spent fuel is not necessary. In 2005 the Energy Commission reaffirmed this finding. The Energy Commission also concluded that reprocessing is more expensive than waste storage and disposal and has "substantial adverse implications for the U.S. effort to halt the proliferation of nuclear weapons" (Energy Commission 2005b, p.85). The Commission's findings are consistent with studies by the National Academies, the National Commission on Energy Policy, the Harvard University Project on Managing the Atom, and the Massachusetts Institute of Technology (MIT) Interdisciplinary Study, all of which concluded that reprocessing is both uneconomic and burdened by substantial proliferation concerns.

In early 2006 the Bush administration and the U.S. Department of Energy proposed the Global Nuclear Energy Partnership (GNEP) with the goal of establishing a

proliferation-resistant nuclear fuel cycle based on a new domestic reprocessing capability. This initiative breaks with the long-standing U.S. practice of relying on the once-through fuel cycle, which does not use reprocessing. While official U.S. policy on reprocessing has reversed several times since the late 1970s, development of a domestic commercial reprocessing capability in the United States has not been seriously pursued since the Carter administration due to a combination of economic and proliferation concerns. The Global Nuclear Energy Partnership would re-introduce domestic reprocessing along with new reactor technologies and global nuclear partnerships.

The Global Nuclear Energy Partnership remains undefined in key respects, and it is far from certain that it will be sustained over the next several years or, if it is, that it will ultimately be successful. Critics question major aspects of the proposal and express concern that, depending on the technologies used, a reprocessing fuel cycle could result in an increase in combined high- and intermediate-level nuclear waste, an increase in the risk of nuclear weapons proliferation, and a significant increase in the cost of nuclear power. Dr. John Deutch, co-chair of the MIT study *The Future of Nuclear Power*, says that the Global Nuclear Energy Partnership "is hugely expensive, hugely misdirected and hugely out of sync" with the needs of the nuclear industry and the nation (Greenwire 2007a).[10] Similarly, the Keystone group consensus report agreed:

> [The Global Nuclear Energy Partnership] is not a credible strategy for resolving either the radioactive waste or proliferation problem…Many questions remain about whether [the Global Nuclear Energy Partnership] will be fully funded by Congress, whether it will succeed in building economically viable facilities if funded, whether the reprocessing path is consistent with industry needs, and whether the proposed contingent fuel assurances would reduce or increase proliferation risk. Questions also remain about whether the proposed technology meets the goals of plutonium protection (Keystone 2007, pp.90-91).

Nuclear Waste Transport

Radioactive waste has been transported safely within the United States for decades. For example, thousands of shipments of transuranic waste have been made to a federal disposal facility in New Mexico. In addition, spent fuel is shipped from research reactors and naval vessels to storage sites, and low-level radioactive waste is shipped from reactor sites and other sources to low-level waste disposal facilities. These shipments provide a framework of experience on which to design the national program for transferring spent fuel from reactor sites across the country to Yucca Mountain. However, the volume of spent fuel that will be shipped to Yucca Mountain is an order of magnitude greater than the volume of spent fuel that has been shipped

[10] John Deutch is an Institute Professor at MIT. He has served over his career in significant government positions, including Director of Central Intelligence and Undersecretary of the U.S. Department of Energy.

in the United States to date. In addition, these shipments will be over greater distances than previous shipments worldwide, over half of which have been domestic shipments within the United Kingdom or France.

Shipments to Yucca Mountain will not begin for at least 10 to 12 years. Based on DOE's estimate that Yucca Mountain will open around 2021, shipments could begin near the end of the current license periods for California's nuclear plants, although shipment schedules are highly uncertain.

DOE has selected a "mostly-rail" transport option for shipments of spent fuel to Yucca Mountain. DOE has announced plans to use "dedicated trains" with restrictions on shipments, has released a design for transport casks, and is investigating routes for the Nevada rail spur. Routes being considered could result in a large number of shipments from eastern states being routed through California.

The Keystone Center group agreed that "transport of spent fuel and other high-level radioactive waste is highly regulated, and that it has been safely shipped in the past. Security requirements during transport have been enhanced in response to 9/11; however, transport security will require continued vigilance" (Keystone 2007, p.80). Similarly, the National Academies found that from a safety perspective spent fuel transport need not pose undue risk if it is managed well, though the National Academies did not evaluate security implications of spent fuel transport due to restrictions on accessing classified documents. The National Academies also cautioned that social effects could ensue along transportation routes if the public lacks confidence in DOE's ability to safely manage the program. These effects could include lower property values, a reduction in tourism, and increased public anxiety.

The *2005 IEPR* recommended that the state evaluate the Department of Energy's proposed use of routes through California to Nevada and reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover state costs for spent fuel shipments. California has repeatedly expressed concerns to DOE over route selection and potential groundwater impacts in California from the repository and has requested that additional public meetings be held in the state; however, DOE has for the most part not been responsive to these concerns.

Costs of Nuclear Power

This report reviews three aspects of nuclear costs: costs of operating nuclear power plants, costs to build new nuclear power plants, and the potential implications of a "nuclear renaissance" on the costs of both new and operating nuclear plants.[11]

[11] This report does not compare the costs of power from nuclear power plants with the costs of power from other sources. For a comprehensive assessment of the levelized costs of power from different sources, see the California Energy Commission draft staff report, *Comparative Costs of California Central Station Electricity Generation Technologies*, CEC-20-2007-011-SD, released June 2007. The draft report is now available from the Energy Commission's website. The final report, when available, will be accessible from this same site: http://www.energy.ca.gov/2007publications/CEC-200-2007-011/CEC-200-2007-011-SD.PDF.

Costs of California Nuclear Power Plants

The California Public Utilities Commission (CPUC) has used both traditional cost-based as well as incentive-based ratemaking for nuclear power plants. While incentive-based ratemaking methods can help shield ratepayers from cost overruns and poor operating performance, they can also make it more difficult to determine the true costs of nuclear plants.[12]

The cost of power from California's nuclear power plants over the upcoming years should be driven largely by the cost of large capital projects, such as the Diablo Canyon and San Onofre steam generator replacement projects, which were approved by the CPUC in 2005. Costs will also be impacted by the effects of these projects on the performance of the plants. Unexpected long-term outages, additional NRC security requirements, and new once-through cooling regulations could also affect overall costs. Ongoing operating costs, such as fuel procurement, spent fuel disposal, security, and decommissioning, were reviewed in substantial detail in the 2005 *Nuclear Power in California: Status Report*.

New Plants: Range of Potential Costs

In the 1950s some predicted that nuclear power would be "too cheap to meter." In the 1980s nuclear power proved in many cases to be a significant financial burden. Today, with the high cost of natural gas, impending limitations on greenhouse gas emissions, and loan guarantees and other significant federal subsidies in the Energy Policy Act of 2005, some utilities are considering another round of commitments to nuclear power.

Development costs for the initial generation of nuclear power plants were very uncertain and generally very high. Development costs for new nuclear plants are again highly uncertain, since there has been very little reactor development in the United States for the past 20 years. Reactor development projects require large capital investments and very long lead times, which contribute to the risk involved in nuclear power plant development.

Cost estimates for new nuclear plants range widely. New developers could face extreme cost overruns comparable to those experienced in the 1980s, especially since no reactors have been built in the United States in nearly 15 years. The rapid inflation experienced in the construction industry over the past five years, which nearly doubled the price of coal plants between 2002 and 2006, bolsters this concern. On the other hand, some developers believe that new technologies, federal subsidies, standardized reactor designs, revised federal licensing procedures, and relatively low interest rates will keep these costs down.

[12] For example, while it is known that PG&E ratepayers paid $34.3 billion (2006 dollars) for power from Diablo Canyon from 1985 through 2006, averaging $99.76 per megawatt-hour, it is unknown if these payments cover (or exceed) PG&E's costs.

Companies considering nuclear power development remain cautious and are focusing on risk mitigation strategies to contain costs. These strategies include reliance on federal loan guarantees, partnering with other entities, entering into risk-sharing contracts with vendors, and seeking cost-recovery assurance from state regulators. Leading investment banks and at least one developer have stated that new nuclear construction projects will have difficulty accessing capital markets unless the federal government accepts **all** the risks for debt through federal loan guarantees. Some state regulators, when asked, have provided only limited cost-recovery assurance for reactor pre-construction and construction costs. The success of risk mitigation strategies in containing a utility or merchant generator's nuclear reactor construction costs will likely be a significant factor in determining whether a significant number of new reactors are built.

Cost Implications of a "Nuclear Renaissance"

Revival of interest in nuclear power is sometimes referred to as a "nuclear renaissance." Such a "renaissance" may pose cost implications for utilities that own nuclear power plants even if they do not build new reactors.

Prices for nuclear fuel have already risen sharply in anticipation of a large worldwide increase in demand. Rapid increase in demand for fuel could lead to temporary fuel shortages, as uranium supplies and enrichment capability have not been developed to meet the demands of a rapidly growing nuclear industry. Most uranium ore and existing enrichment capacity are offshore, raising questions of availability to U.S. nuclear operators.

Shortages of skilled workers and key reactor materials and components could also hinder reactor development, as there is limited worldwide production capacity for some of the highly specialized reactor components. An increase in demand could affect owners of currently operating nuclear plants that need to replace specialized reactor components. New reactor development could also increase the demand for skilled labor beyond available supply. As noted by AREVA and others, the nuclear industry is an aging industry and will require 10,000 to 20,000 new people over the next four to five years (EIR 2006). The industry estimates that about 40 percent of the nuclear work force will retire within the next five years.

Utilities can stem cost increases by running plants efficiently and with high capacity factors and by using effective hedging and management strategies. For example, utilities can use long-term fuel contracts, material procurement and management strategies, and proactive employee training and retention programs to keep costs down and to limit disruptive shortages in nuclear fuel or skilled labor.

Environmental and Societal Impacts of Nuclear Power

Nuclear power poses costs to society in addition to the costs posed to ratepayers and developers. Two major categories of societal costs are the environmental impacts and security risks associated with nuclear plants.

Nuclear Power and the Environment

The past few years have seen a resurgence of interest in nuclear power as part of a strategy for reducing greenhouse gas emissions and global warming. However, while emissions directly associated with electricity generation are low, nuclear generation poses other environmental risks, including aquatic impacts from once-through cooling (if used); groundwater contamination with tritium; radiation hazards associated with disposal of radioactive waste; and risks of radioactive releases triggered by earthquakes, tsunamis, accidents, or sabotage. There are also environmental impacts associated with the infrastructure of activities that support nuclear power, the "nuclear life cycle," which starts with uranium mining and extends through reactor construction and operation to spent fuel storage/disposal or reprocessing and, finally, decommissioning. In addition, there is the difficult-to-quantify risk of the spread of nuclear weapons capability, which Dr. John Holdren has described as "an awesome social cost indeed" (ARE 1976, p.564; ARE 1980, p.245).

Nevertheless, nuclear power under normal operation produces lower greenhouse gas and pollutant emissions than fossil-fueled power. In particular, the life cycle greenhouse gas emissions from nuclear power production appear to be much lower than from either coal or natural gas generated power and of a similar order of magnitude as those from solar generated power. Nuclear power is thus seen by some as an important tool for reducing greenhouse gas emissions. Others argue that nuclear power should have no role in a long-term, low-carbon energy strategy, while still others take an agnostic approach and neither rule out nuclear power nor embrace it wholeheartedly.

Supporters and opponents of nuclear power both emphasize the importance of using a variety of technologies to combat global warming. Supporters argue against closing off any major option, including nuclear power. Opponents argue that nuclear power development could divert investments from low carbon power alternatives, such as renewable energy and energy efficiency, which could be deployed more quickly and more cheaply than new nuclear reactors.[13]

Given the limited knowledge of future energy costs and benefits, the best path now may be to pursue all options, as stated by Dr. Holdren:

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[13] For example, while a June 2007 Electric Power Research Institute (EPRI) study found that increased reliance on nuclear power would lower the cost of reducing greenhouse gas emissions, a 2006 UK Sustainable Development Commission (UK SDC) study found that the UK's greenhouse gas reduction goals could be met with less public risk by using other technologies (EPRI 2007e, p.1-5; UK SDC 2006c, p.19). The cost assumptions supporting EPRI's conclusions are not documented, and EPRI has not yet responded to requests to provide them. The UK SDC did not rely on a single cost estimate; rather, the study found that nuclear power costs remain subject to significant uncertainty and cannot be realistically assessed at the present time. These and other analyses are described further in the body of this report.

> [Society] might decide that the combination of improved energy efficiency, advanced fossil fuel technologies and renewable energy technologies of a variety of kinds can meet this challenge without nuclear energy. My position is agnostic on this, we don't know yet what the best mix is, we should be trying to fix the problems of fission to see if we want it to be a part of this mix and at the same time we should be pursuing with tremendous vigor the possibilities available to us in improving energy efficiency, in renewable energy options, and in advanced fossil fuel technologies (ABC Radio 2002).

The Keystone group consensus recommendation added that a carbon tax or a cap and trade approach to valuing greenhouse gas reductions could enhance the position of all low-carbon resources and put them in competition with each other.

Security for Reactors and Spent Fuel

The protection of nuclear power plants and spent fuel storage facilities from land-based, water-based, and air-based assaults has received greater attention in the wake of the terrorist attacks of September 11, 2001. This heightened concern over security has been reinforced by extensions of operating reactors' licenses, renewed interest in building new nuclear plants, prospects of increased nuclear waste transport, and ever-growing stockpiles of spent fuel.

Spent fuel stored at the reactor site is not protected by the containment structure that surrounds the reactor core, and some critics argue that an attack on a spent fuel pool could breach the pool's concrete walls, potentially releasing harmful levels of radioactive material to the surrounding area. Dry cask storage facilities are considered safer than spent fuel pools, though spent fuel generally must remain five years in pool storage before being transferred to dry casks.

In 2004 the National Commission on Energy Policy made the following observation about nuclear safety and security:

> Nuclear power reactors of contemporary design have compiled an excellent safety record. If the number of nuclear reactors in the United States is to double or triple over the next 30 to 50 years, however, and the number worldwide is to grow ten-fold…one would want the probability of a major release of radioactivity, measured per reactor per year, to fall a further ten-fold or more. This means improved defenses against terrorist attack as well as against malfunction and human error…License extensions for existing plants and the issuance of licenses for new plants should be contingent on the NRC's affirmative judgment that that the plants…[are] adequately resistant to terrorist attack (NCEP 2004, pp.58, 60).

The NRC has taken a number of steps to improve the security of nuclear power plants. The agency struggles to balance the concerns of plant operators that additional requirements are excessive with critics' complaints that the same

requirements are inadequate. This struggle is made worse because the NRC process for addressing security issues has not always been transparent, even to governmental or quasi-governmental organizations such as the U.S. Government Accountability Office (GAO) and the National Academies. A case in point is the NRC's failure to publicly support its conclusion that current U.S. reactors would withstand an aircraft attack with a very low probability of radiation release, while some professional studies appear to have come to very different conclusions.

Similarly, the secrecy of the NRC with regard to GAO and the National Academies' expert panels investigating the security of spent fuel transportation and storage has made it difficult to develop public confidence in NRC actions regarding spent fuel security. Critics question the adequacy of NRC security regulations. The California and Massachusetts attorneys general have filed petitions requesting that the impact of terrorism on spent fuel pools be considered in all licensing decisions that involve high-density pool storage.

The appropriate level of transparency for security-related issues can be difficult to find. As noted in the Keystone report, "[transparency] is a key cornerstone for public trust-building. However, when it comes to the security of nuclear power plants, full disclosure may be counterproductive" (Keystone 2007, p.57). In fact, the appropriateness of the NRC's secrecy with regard to security measures and the adequacy of security systems and procedures at operating reactors are among the few major issues regarding which the Keystone Center's experts could not arrive at a consensus (Keystone 2007, p.53).

Nuclear Power in the Coming Years

The future contribution of nuclear power to electricity generation in the United States depends largely on three factors: the reliability of current reactors, the number of these reactors that operate past their initial license periods, and whether new reactors are built.

Reliability

The aging of the U.S. fleet of nuclear power reactors presents challenges in terms of the reliability, safety, and performance of nuclear power plants. In recent years, U.S. nuclear plants have proven to be reliable generation sources, with an average availability rate of 90 percent in 2006. However, some plants have experienced significant difficulties and poor availability. In all, of the 130 nuclear reactors ever licensed in the United States, 41 (including San Onofre Unit 1 in California) have experienced at least one outage lasting a year or more.

Industry critics argue that the current reactor oversight process is ineffective at spotting and preventing problems before they require expensive repairs and extended shutdowns. If correct, reliability levels at a plant could decrease with little warning. This is the case at Palo Verde, where the plant's capacity factor fell unexpectedly from 94 percent in 2002 to 77 percent in 2005.

Two primary watchdogs oversee the performance and safety of U.S. nuclear power plants: the NRC and a private organization established by the nuclear industry, the Institute for Nuclear Power Operations (INPO). The Palo Verde experience is instructive. The NRC ranked the plant in the highest of five performance categories through 2004, though the plant's performance had been declining for two years. While the Institute for Nuclear Power Operations' performance evaluations are kept in strict confidence, the continued decline in performance at Palo Verde suggests that the Institute for Nuclear Power Operations, too, was late in identifying emerging problems at the plant or was not effective at setting in place appropriate corrective actions in a timely fashion.[14] This may reflect the difficulty in changing an organization's culture: complacency and a "weak safety culture" have been identified as root causes of Palo Verde's decline.

The implications of that decline for California could be significant. Palo Verde Unit 3 has been assigned to the fourth-lowest of the five NRC performance categories. Further demotion to the fifth and final category would trigger temporary closure.

The Future of Nuclear Power in the United States

Commercial nuclear power is experiencing a wave of renewed interest and support. About half the power plants in the United States have received license renewals to extend their operating licenses by 20 years. There is interest among some U.S. utilities in building new nuclear plants, driven by a number of federal policy initiatives, federal loan guarantees and other financial incentives in the Energy Policy Act of 2005, increased fossil fuel prices and reduced availability, continuing energy demand growth, and concerns regarding global climate change.

The license renewal process focuses on ensuring that plant aging will not degrade reactor safety and that significant environmental impacts will not ensue from the license renewal. Cooling water impacts are among the environmental impacts considered; however, the NRC defers to state or regional water regulators to evaluate and address once-through cooling impacts. Some other issues of concern to the State of California, such as seismic safety and terrorist risks, are not considered in the context of license renewal, and the NRC will not grant hearings to consider these issues as it deems them to be beyond the scope of the proceeding. In fact, requests for hearings on any issue are rarely granted—no hearings have yet been held in a license renewal case, though several are expected in the coming year. When held, the hearings will be very limited. There will be no traditional discovery and no guarantee of an opportunity to question witnesses.

Given the limitations of the current license renewal process, some states are pursuing options to fashion a role in considering license renewal. While the NRC

[14] There has been limited disclosure of INPO rankings. PG&E has reported that Diablo Canyon's rankings were downgraded to 82.5 in 2002 and have since recovered to 96.19. SCE has not disclosed any information about the rankings of San Onofre or Palo Verde.

says it would challenge a state's attempt to block a license renewal, state agencies can play a role in deciding whether a utility can recover the costs to apply for or use an extended operating license. For example, the California Public Utilities Commission has ruled that PG&E can recover costs to begin a license renewal feasibility study and must apply for permission before actually applying for license renewal. Southern California Edison intends to follow the same procedure if it seeks a license renewal for San Onofre.

Meanwhile, the first new U.S. reactors in 30 years are being planned, and research is underway to improve the economics, performance, and safety of the next generation of nuclear reactors. If no new reactors are built in the United States, the last units in the U.S. nuclear fleet will cease operating by 2056, even if all currently operating reactors receive 20-year license renewals.

Implications for California

Nuclear power as an electric resource option has gained visibility in the two years since the release of the *2005 IEPR*. The body of this report provides a factual background for assessing the nuclear power option for California, given the state's current resource situation and the nuclear policy embodied in the 1976 nuclear statutes. This section assesses how California may be affected by the issues described in this report and how the state and the Energy Commission might respond.

In identifying implications for California, the findings and recommendations made by the Energy Commission in the *2005 IEPR* were used as a foundation. The assessment presented here is intended as a starting point for the IEPR Committee in considering its findings on nuclear power for the *2007 IEPR*. In addition to this report, a substantial record is available to the IEPR Committee: the *2005 IEPR* and associated record, the two-day June 2007 workshop on nuclear issues and public comments on the draft of this report and on the Committee's questions before the workshop.[15]

New and Existing Nuclear Power Plants in California

The Legislature should develop a suitable framework for reviewing the costs and benefits of nuclear power plant license extensions and clearly delineate agency responsibilities, scope of evaluation, and the criteria for assessment.

In light of California's moratorium on nuclear power development, until progress is made in disposing of or reprocessing spent fuel, the Energy Commission could not

[15] These documents are all located on the Energy Commission's website. The *2005 IEPR* may be found here: http://energy.ca.gov/2005publications/CEC-100-2005-007/CEC-100-2005-007-CMF.PDF. Documents related to the *2007 IEPR*, including the draft consultant report, transcripts to the workshops, and public comments, may be found here: http://energy.ca.gov/2007_energypolicy/documents/index.html#06252807.

provide land-use permits or certification for a new nuclear plant at this time, nor will they likely be able to do so in the near future.

Spent Fuel Reprocessing and Implications for California

At this time the Energy Commission can conclude that reprocessing is still substantially more expensive than waste storage and disposal and that it has substantial implications for U.S. efforts to halt the proliferation of nuclear weapons material.

The Energy Commission should continue to monitor the progress of the Global Nuclear Energy Partnership and its various components.

The state, and specifically the Energy Commission, should convey to the federal government its preferred order of priorities for federal research development and demonstration programs, consistent with the goals set forth in the Energy Action Plan and in the 2003 and 2005 *Integrated Energy Policy Reports*.

Waste Storage and Disposal and Implications for California

At this time the Energy Commission has no basis to conclude that DOE will succeed in opening the permanent repository at Yucca Mountain in the near future. Until a permanent repository at Yucca Mountain or at an alternative location either begins operation or can be credibly expected to begin operation using a demonstrated disposal technology, the Commission cannot find that the federal government has approved and that there exists a demonstrated technology for the permanent disposal of spent fuel from these facilities. DOE's failure to license and operate a permanent repository has imposed substantial costs on California consumers who have paid over $1 billion to the federal government for this service and have had to incur the costs of building and operating interim fuel storage facilities.

The state should devote increased resources to allow it to take an active role in the Yucca Mountain licensing proceeding, currently planned to begin in June 2008 to ensure that California's interests are protected.

The state should challenge DOE's inadequate response to potential impacts identified in California's comments during the Yucca Mountain Environmental Impact Statement and license review process.

California has limited options for the storage and disposal of low-level nuclear waste. California utilities may need to indefinitely store certain classes of low-level nuclear waste at their nuclear power plants until offsite disposal facilities become available.

Consequences of Failure to Develop Yucca Mountain

The state should encourage the utilities to continue to seek damages from DOE to recover costs paid by California ratepayers to build and operate interim waste storage facilities.

The state should monitor developments at the Diablo Canyon interim spent fuel storage facility and the likelihood that its operation will be delayed for an extended period due to challenges to the facility license.

The state should consider the implications of conflicting information regarding the vulnerability to terrorist attacks or sabotage of spent fuel pools, spent fuel shipments, and interim spent fuel dry cask storage facilities, and the state should encourage the NRC to work with a National Academies' panel of experts to resolve these concerns. The state should also consider other means to ensure that a comprehensive National Academies study of the implications of terrorism for both at-reactor spent fuel storage and spent fuel transportation is performed, such as a request to the U.S. Department of Homeland Security or the Government Accountability Office.

Spent Fuel Transportation

The state should evaluate DOE's proposed increased use of California routes to transport nuclear waste to and from Nevada.

The Energy Commission should continue its participation in collaborative processes at the national and regional level to ensure that California's interests are represented.

The Energy Commission should also continue to coordinate the California Interagency Transport Working Group to initiate state needs assessments and to plan and prepare for spent fuel shipments and other large radioactive shipments in California.

The Energy Commission should continue to participate in DOE's route selection and transportation planning proceedings.

As recommended in 2005, the state should reexamine the adequacy of California's nuclear transport fees and federal funding programs to cover the state's costs of spent fuel shipments.

The state should continue to work with other states and with DOE to ensure that DOE provides states with timely and sufficient information on projected shipments, routes, and plans, as well as the flexibility and support that the state needs to prepare for shipments.

Environmental Impacts of Nuclear Power Plants

The Energy Commission has conducted detailed reviews of the status of nuclear power for the 2005 and 2007 *Integrated Energy Policy Reports*, including an examination of life cycle environmental impacts, and is poised to perform the nuclear power plant assessment required by AB 1632. The Energy Commission should consider both greenhouse gas implications and life cycle environmental impacts as the state continues to refine and extend its preferred loading order for energy

technologies and works to implement the policies of meeting California's increasing electricity needs, maintaining a portfolio of reliable energy supplies, and reducing the greenhouse gas emissions of its power sector.

The Energy Commission should continue to assess the reliability implications of federal and state once-through cooling regulations on Diablo Canyon and San Onofre.

Reliability of California's Nuclear Power Plants

California utilities should be directed to develop power supply contingency plans in the event that performance degradation at the state's nuclear power plants leads to prolonged plant outages, particularly at Palo Verde.

The Energy Commission should work with federal and state regulators, nuclear plant owners, and the Institute for Nuclear Power Operations to develop a means for usefully incorporating results of Institute for Nuclear Power Operations reviews and ratings of reactor operations into a meaningful public process while maintaining the value of these reviews as confidential and candid assessments.

Potential Expansion of Nuclear Power

The state should continue to monitor the status of DOE's programs that support new nuclear power development and the cost and progress of new reactor development in the United States. When more information is available, the state should seek to determine the fuel cycle costs and performance of advanced reactors.